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From Data to Decisions:
A Hybrid CRITIC-GRA Model for Communication Effectiveness Evaluation of Huimo Production Techniques

Yuqing Xia
Academy of Art and Design, Anhui University of Technology, Maanshan, China

Xing Yang
School of Arts and Design, Huizhou University, Huizhou, China

Zhipeng Cai
http://orcid.org/0009-0003-9452-1260
Faculty of Humanities and Arts, Macau University of Science and Technology, Macau, China

Hong Tang
School of Design and Art, Sichuan Technology and Business College, Chengdu, China
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ABSTRACT

Within the realm of digital communication, evaluating the effectiveness of promoting traditional craftsmanship, such as Huimo production, is treated as a multi-attribute decision-making problem. This study introduced an enhanced grey relational analysis (GRA) model integrated with neutrosophic cubic sets—a structure adept at capturing uncertainty, inconsistency, and conflicting data. Attribute weights were objectively assigned via the Criteria Importance Through Intercriteria Correlation approach to minimize bias. An upgraded neutrosophic cubic number (NCN)-GRA framework was developed along with a detailed stepwise computation process. A practical application investigating the digital promotion of Huimo production validated the model's relevance in contemporary educational settings, integrating diverse criteria aligned with present-day pedagogical goals. Comparative analyses verified that the proposed NCN-GRA technique outperformed existing models, showcasing greater reliability and precision when addressing complex decision-making environments. The research provides valuable insights for improving the assessment of communication approaches related to intangible cultural heritage in the digital age.

KEYWORDS

Multi-Attribute Decision Making, Neutrosophic Cubic Sets, Grey Relational Analysis Framework, Communication Effectiveness Evaluation, Huimo Production Techniques

INTRODUCTION

Multi-attribute decision-making (MADM) serves as a structured methodological approach designed to assess, compare, and ultimately select optimal choices from a range of alternatives by evaluating them against diverse and often competing criteria (Kousar & Kausar, 2025; Palanikumar et al., 2025; Senapati et al., 2023; H. L. Wang et al., 2023). Its application spans numerous domains—

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including corporate management, engineering design, educational policy, and healthcare systems—where decisions must balance multifaceted and frequently contradictory objectives (Hussain et al., 2023; Ihsan et al., 2023; Ning et al., 2023). The central aim of MADM is to offer a coherent and reproducible process that assists decision-makers in integrating both measurable and subjective factors to classify and rank available options effectively. The MADM procedure generally commences with a clear articulation of the decision problem and the enumeration of viable alternatives. This is followed by the identification of pertinent evaluation attributes that capture critical dimensions of performance or value (Lei et al., 2023; Verma & Alvarez-Miranda, 2024; H. L. Wang et al., 2024; J. Wang et al., 2024). To account for varying levels of importance among these criteria, weighting mechanisms are applied. These can be established through objective computational techniques such as the Criteria Importance Through Intercriteria Correlation (CRITIC) method (Diakoulaki et al., 1995), which uses data-driven contrast analysis, or through subjective channels including deliberative expert consultation. With the criteria and weights specified, the next step involves gathering performance data for every alternative relative to each attribute. The nature of this information can vary significantly—ranging from exact quantitative measurements and categorical ratings to imprecise, ambiguous, or linguistically expressed values—depending on the context and complexity of the decision environment (N. Ali et al., 2024; N. Ali et al., 2023). A suite of analytical techniques is available to process this information and generate comparative rankings. Among the most widely adopted are the analytic hierarchy process, which decomposes decisions into hierarchical structures; the Technique for Order of Preference by Similarity to Ideal Solution, which evaluates alternatives based on proximity to an ideal outcome (Lu et al., 2019); and grey relational analysis (GRA), which examines the degree of similarity between alternative sequences and a reference sequence. These methodologies synthesize multi-dimensional data into unified scores or ordinal rankings, facilitating the identification of the most desirable option. In cases where input data are characterized by incompleteness, vagueness, or inconsistency, advanced hybrid frameworks—such as those integrating fuzzy set theory, neutrosophic logic, or other uncertainty-aware formalisms—are employed to enhance the reliability and applicability of the decision process (Chamodrakas et al., 2011; Park et al., 2011; Zavadskas et al., 2010). As an integral component of modern operational research and decision science, MADM enhances the rigor, transparency, and accountability of complex selections. By systematically illuminating trade-offs, strengths, and limitations across alternatives, it empowers stakeholders to make well-reasoned and justifiable decisions that align with overarching strategic goals (Sun et al., 2023; Zhang et al., 2023).

In the digital era, assessing the dissemination effectiveness of Huimo production techniques is commonly characterized as a MADM challenge. Despite this, current literature reveals a notable absence of research employing the neutrosophic cubic number-based grey relational analysis (NCN-GRA) approach for such evaluations. This identified gap highlights the necessity of adapting GRA within the structure of neutrosophic cubic sets (NCSs; M. Ali et al., 2016) to better address the uncertainty, indeterminacy, and intricate data conflicts typical of these assessments. With the growing emphasis on aligning educational outcomes with industry needs under the concept of industry-education integration, establishing a trustworthy and effective evaluation mechanism has become increasingly important. Employing NCSs to evaluate the communication effectiveness of Huimo production craftsmanship in the digital era offers two distinct advantages. Firstly, NCSs provide a superior three-dimensional data representation, simultaneously characterizing the truth, indeterminacy, and falsity membership degrees of evaluation information. This multifaceted modeling is exceptionally adept at capturing the inherent uncertainties and subjective ambiguities present in assessing intangible cultural heritage dissemination, such as fluctuating audience engagement and varied interpretive understanding, which traditional fuzzy sets fail to fully encapsulate. Secondly, the cubic structure—comprising interval neutrosophic sets and single-valued neutrosophic sets—enables a more dynamic and flexible analytical framework. This allows evaluators to process complex, hybrid data from digital platforms, integrating both precise metrics and imprecise expert judgments.

Consequently, it yields a more comprehensive and reliable assessment, significantly enhancing the accuracy and depth of understanding the propagation impact of this traditional craft.

This study aimed to bridge this research void by proposing a structured MADM methodology grounded in NCN-GRA. Capitalizing on the expressive power of NCSs, the introduced framework enhances the capability to process imprecise and contradictory decision information reliably. The main contributions of this work consist of a systematic elaboration of the NCN-GRA technique and its implementation in evaluating competency—particularly in innovation and entrepreneurship—within digitally-mediated educational environments. Empirical results confirmed that the model delivers precise and actionable insights, supporting a more responsive evaluation system attuned to contemporary industrial and pedagogical requirements. To achieve this goal, the following highlights of the study are presented.

Attribute Weight Determination Using CRITIC

The CRITIC approach was utilized to impartially determine the weights of attributes, guaranteeing an accurate representation of each criterion's importance. This model significantly strengthened the precision and dependability of the decision-making mechanism, leading to more resilient and well-founded evaluations.

Development of NCN-GRA Under NCSs

Developed within the framework of NCSs, the NCN-GRA approach is adept at managing the uncertainty, vagueness, and indeterminacy common in real-world decision scenarios. By focusing on sequence similarity, it provides a flexible and powerful tool for assessing and differentiating among various alternatives.

Practical Application and Comparative Analysis

To demonstrate the applicability of the proposed model, a case study on evaluating the communication effectiveness of Huimo production techniques in the digital environment was conducted. The example served to verify the practicality and advantages of the NCN-GRA framework. Furthermore, comparative assessments revealed significant improvements in computational efficiency, adaptability to uncertainty, and consistency in producing trustworthy results—setting it apart from conventional evaluation approaches.

PRELIMINARIES

M. Ali et al. (2016) designed the NCSs based on SVNSs (H. Wang et al., 2010) and IVNSs (H. Wang et al., 2005).

Definition 1 (M. Ali et al., 2016)

The NCSs were designed:

$$A = \left\{\left(\vartheta, \left(I_A(\vartheta), S_A(\vartheta)\right)\right) | x \in X\right\} \tag{1}$$

where $I_A(\vartheta)$ is the IVNSs and $S_A(\vartheta)$ is the SVNSs.

$$I_A(\vartheta) = \left(\left[TL_A(\vartheta), TR_A(\vartheta)\right], \left[IL_A(\vartheta), IR_A(\vartheta)\right], \left[FL_A(\vartheta), FR_A(\vartheta)\right]\right) \tag{2}$$

$$S_A(\vartheta) = \left(TT_A(\vartheta), II_A(\vartheta), FF_A(\vartheta)\right) \tag{3}$$

$$\left[TL_A(\vartheta), TR_A(\vartheta)\right], \left[IL_A(\vartheta), IR_A(\vartheta)\right], \left[FL_A(\vartheta), FR_A(\vartheta)\right] \subseteq [0,1] \tag{4}$$

$$TT_A(\vartheta), II_A(\vartheta), FF_A(\vartheta) \in [0,1] \tag{5}$$

$$0 \leq TR_A(\vartheta) + IR_A(\vartheta) + FR_A(\vartheta) \leq 3,$$

$$0 \leq TT_A(\vartheta) + II_A(\vartheta) + FF_A(\vartheta) \leq 3 \tag{6}$$

The neutrosophic cubic number (NCN) was designed: $A = \{([TL_A, TR_A], [IL_A, IR_A], [FL_A, FR_A]), (TT_A, II_A, FF_A)\}$.

Definition 2 (M. Ali et al., 2016)

Let $SA = \{([TL_A, TR_A], [IL_A, IR_A], [FL_A, FR_A]), (TT_A, II_A, FF_A)\}$ and $SB = \{([TL_B, TR_B], [IL_B, IR_B], [FL_B, FR_B]), (TT_B, II_B, FF_B)\}$. The operations laws were designed:

$$SA \oplus SB = \left\{ \begin{pmatrix} (TL_A + TL_B - TL_A TL_B, TR_A + TR_B - TR_A TR_B), \\ [IL_A IL_B, IR_A IR_B], [FL_A FL_B, FR_A FR_B] \end{pmatrix}, \begin{pmatrix} TT_A + TT_B - TT_A TT_B, \\ II_A II_B, FF_A FF_B \end{pmatrix} \right\};$$

$$SA \otimes SB = \left\{ \begin{pmatrix} [TL_A TL_B, TR_A TR_B], \\ [IL_A + IL_B - IL_A IL_B, IR_A + IR_B - IR_A IR_B], \\ [FL_A + FL_B - FL_A FL_B, FR_A + FR_B - FR_A FR_B] \end{pmatrix}, \begin{pmatrix} TT_A TT_B, \\ II_A + II_B - II_A II_B, \\ FF_A + FF_B - FF_A FF_B \end{pmatrix} \right\};$$

$$\lambda SA = \left\{ \begin{pmatrix} \left[1 - (1 - TL_A)^\lambda, 1 - (1 - TR_A)^\lambda\right], \\ \left[(IL_A)^\lambda, (IR_A)^\lambda\right], \left[(FL_A)^\lambda, (FR_A)^\lambda\right] \end{pmatrix}, \begin{pmatrix} 1 - (1 - TT_A)^\lambda, \\ (II_A)^\lambda, (FF_A)^\lambda \end{pmatrix} \right\}, \lambda > 0;$$

$$(SA)^\lambda = \left\{ \begin{pmatrix} \left[(TL_A)^\lambda, (TR_A)^\lambda\right], \\ \left[1 - (1 - IL_A)^\lambda, 1 - (1 - IR_A)^\lambda\right], \\ \left[1 - (1 - FL_A)^\lambda, 1 - (1 - FR_A)^\lambda\right] \end{pmatrix}, \begin{pmatrix} (TT_A)^\lambda, \\ 1 - (1 - II_A)^\lambda, \\ 1 - (1 - FF_A)^\lambda \end{pmatrix} \right\}, \lambda > 0. \tag{6}$$

Definition 3 (Ajay et al., 2020)

Let $SA = \{([TL_A, TR_A], [IL_A, IR_A], [FL_A, FR_A]), (TT_A, II_A, FF_A)\}$. The score, accuracy, and certainty values were designed:

$$DSV(SA) = \frac{(6 + TL_A + TR_A + TT_A - IL_A - IR_A - FL_A - FR_A - II_A - FF_A)}{9} \tag{7}$$

$$DAV(SA) = \frac{(TL_A + TR_A + TT_A - IL_A - IR_A - FF_A)}{3} \tag{8}$$

$$DCV(SA) = \frac{(TL_A + TR_A + TT_A)}{3} \tag{9}$$

Definition 4 (Ajay et al., 2020)

Let SA= {([TL_A,TR_A], [IL_A,IR_A], [FL_A,FR_A]), (TT_A,II_A,FF_A)} and SB= {([TL_B,TR_B], [IL_B,IR_B], [FL_B,FR_B]), (TT_B,II_B,FF_B)}. Then, the comparison for NCNs was designed:

- If $DSV(SA)<DSV(SB)$, then, $SA<SB$.
- If $DSV(SA)=DSV(SB)$, and $DAV(SA)<DAV(SB)$, $SA<SB$.
- If $DSV(SA)=DSV(SB)$, and $DAV(SA)=DAV(SB)$, and $DCV(SA)<DCV(SB)$, $SA<SB$.
- If $DSV(SA)=DSV(SB)$, and $DAV(SA)=DAV(SB)$, and $DCV(SA)=DCV(SB)$, $SA=SB$.

Definition 5 (Pramanik et al., 2017)

Let SA= {([TL_A,TR_A], [IL_A,IR_A], [FL_A,FR_A]), (TT_A,II_A,FF_A)} and SB= {([TL_B,TR_B], [IL_B,IR_B], [FL_B,FR_B]), (TT_B,II_B,FF_B)}. Then, the normalized Hamming distance was designed:

$$HD(SA,SB) = \frac{1}{9}\begin{pmatrix} |TL_A - TL_B| + |TR_A - TR_B| + |IL_A - IL_B| + \\ |IR_A - IR_B| + |FL_A - FL_B| + |FR_A - FR_B| + \\ |TT_A - TT_B| + |II_A - II_B| + |FF_A - FF_B| \end{pmatrix} \tag{10}$$

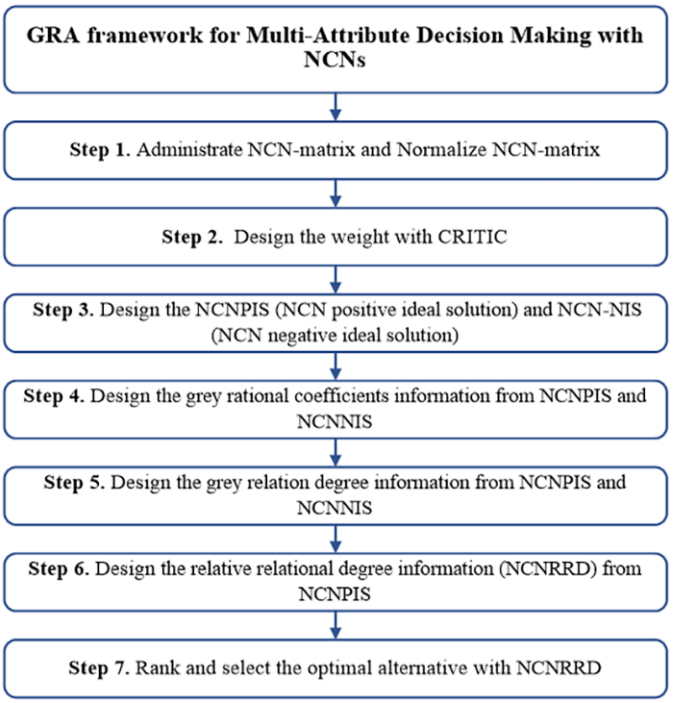
GRA FRAMEWORK FOR MADM WITH NCNS

The NCN-GRA framework was designed for MADM. Let YY= {YY_1,YY_2,….,YY_m} be alternatives. Let ZZ= {ZZ_1,ZZ_2,…,ZZ_n} be attributes, wz= {wz_1,wz_2,…,wz_n} be weight information for ZZ_j, and $wz_j \in [0,1], \sum_{j=1}^{n} wz_j = 1$.

$$QQ = \left(qq_{ij}\right)_{m\times n} = \left\{\left(\left[TL_{ij}, TR_{ij}\right], \left[IL_{ij}, IR_{ij}\right], \left[FL_{ij}, FR_{ij}\right]\right), \left(TT_{ij}, II_{ij}, FF_{ij}\right)\right\}_{m\times n}$$

is the NCN-matrix. The calculating steps were designed as shown in Figure 1.

Figure 1 Grey Relational Analysis Framework for Multi-Attribute Decision-Making Under Neutrosophic Cubic Numbers


GRA framework for Multi-Attribute Decision Making with NCNs
Step 1. Administrate NCN-matrix and Normalize NCN-matrix
Step 2. Design the weight with CRITIC
Step 3. Design the NCNPIS (NCN positive ideal solution) and NCN-NIS (NCN negative ideal solution)
Step 4. Design the grey rational coefficients information from NCNPIS and NCNNIS
Step 5. Design the grey relation degree information from NCNPIS and NCNNIS
Step 6. Design the relative relational degree information (NCNRRD) from NCNPIS
Step 7. Rank and select the optimal alternative with NCNRRD

Note. CRITIC = Criteria Importance Through Intercriteria Correlation; GRA = grey relational analysis; NCN = neutrosophic cubic number.

Step 1: Normalize the $QQ = \left(qq_{ij}\right)_{m\times n}$ to $NQ = \left[nq_{ij}\right]_{m\times n}$.

$$nq_{ij} = \left\{\left(\left[TL_{ij}, TR_{ij}\right], \left[IL_{ij}, IR_{ij}\right], \left[FL_{ij}, FR_{ij}\right]\right), \left(TT_{ij}, II_{ij}, FF_{ij}\right)\right\}$$

$$= \begin{cases} \left\{\begin{matrix}\left(\left[TL_{ij}, TR_{ij}\right], \left[IL_{ij}, IR_{ij}\right], \left[FL_{ij}, FR_{ij}\right]\right), \\ \left(TT_{ij}, II_{ij}, FF_{ij}\right)\end{matrix}\right\} & ZZ_j \text{ is benefit criterion} \\ \left\{\begin{matrix}\left(\left[FL_{ij}, FR_{ij}\right], \left[1-IR_{ij}, 1-IL_{ij}\right], \left[TL_{ij}, TR_{ij}\right]\right), \\ \left(FT_{ij}, 1-II_{ij}, TF_{ij}\right)\end{matrix}\right\} & ZZ_j \text{ is cost criterion} \end{cases} \tag{11}$$

Step 2: The CRITIC framework (Diakoulaki et al., 1995) was designed to obtain the weights. The NCN correlation coefficient values (NCNCCV) were designed:

$$NCNCCV_{jt} = \frac{\sum_{i=1}^{m}\left(DSV(nq_{ij}) - SV(nq_j)\right)\left(DSV(nq_{it}) - SV(nq_t)\right)}{\sqrt{\sum_{i=1}^{m}\left(DSV(nq_{ij}) - SV(nq_j)\right)^2}\sqrt{\sum_{i=1}^{m}\left(DSV(nq_{it}) - SV(nq_t)\right)^2}}, \tag{12}$$

$j, t = 1,2,\ldots,n,$

where $DSV\left(nq_j\right) = \frac{1}{m}\sum_{i=1}^{m} DSV\left(nq_j\right)$, $DSV\left(nq_t\right) = \frac{1}{m}\sum_{i=1}^{m} DSV\left(nq_{it}\right)$.

Design the NCNSDV (NCN standard deviation values):

$$NCNSDV_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(DSV(nq_{ij}) - DSV(nq_j)\right)^2} \tag{13}$$

where $DSV\left(nq_j\right) = \frac{1}{m}\sum_{i=1}^{m} DSV\left(nq_{ij}\right)$.
Design the weight information:

$$wz_j = \frac{NCNSDV_j \sum_{t=1}^{n}\left(1 - NCNCCV_{jt}\right)}{\sum_{j=1}^{n}\left(NCNSDV_j \sum_{t=1}^{n}\left(1 - NCNCCV_{jt}\right)\right)} \tag{14}$$

where $wz_j \in [0,1]$, $\sum_{j=1}^{n} wz_j = 1$.

Step 3: Design the NCNPIS (NCN positive ideal solution) and NCN-NIS (NCN negative ideal solution):

$$NCNPIS = \left\{NCNPIS_j\right\}, j = 1,2,\ldots,n. \tag{15}$$

$$NCNNIS = \left\{NCNNIS_j\right\}, j = 1,2,\ldots,n. \tag{16}$$

$$NCNPIS_j = \left\{\left(\left[TL_j^+, TR_j^+\right], \left[IL_j^+, IR_j^+\right], \left[FL_j^+, FR_j^+\right]\right), \left(TT_j^+, II_j^+, FF_j^+\right)\right\} \tag{17}$$

$$NCNNIS_j = \left\{\left(\left[TL_j^-, TR_j^-\right], \left[IL_j^-, IR_j^-\right], \left[FL_j^-, FR_j^-\right]\right), \left(TT_j^-, II_j^-, FF_j^-\right)\right\} \tag{18}$$

$$NCNPIS_j = \max_j DSV\left\{\left(\left[TL_{ij}, TR_{ij}\right], \left[IL_{ij}, IR_{ij}\right], \left[FL_{ij}, FR_{ij}\right]\right), \left(TT_{ij}, II_{ij}, FF_{ij}\right)\right\} \tag{19}$$

$$NCNNIS_j = \min_j DSV\left\{\left(\left[TL_{ij}, TR_{ij}\right], \left[IL_{ij}, IR_{ij}\right], \left[FL_{ij}, FR_{ij}\right]\right), \left(TT_{ij}, II_{ij}, FF_{ij}\right)\right\} \tag{20}$$

Step 4: Design the grey rational coefficients information from NCNPIS and NCNNIS:

$$PISGRC\left(YY_{ij}\right) = \frac{\min_{1\le i\le m}\min_{1\le j\le n} HD\left(nq_{ij}, NCNPIS_j\right) + \rho \max_{1\le i\le m}\max_{1\le j\le n} HD\left(nq_{ij}, NCNPIS_j\right)}{HD\left(nq_{ij}, NCNPIS_j\right) + \rho \max_{1\le i\le m}\max_{1\le j\le n} HD\left(nq_{ij}, NCNPIS_j\right)} \tag{21}$$

$$NISGRC\left(YY_{ij}\right) = \frac{\min_{1\le i\le m}\min_{1\le j\le n} HD\left(nq_{ij}, NCNNIS_j\right) + \rho \max_{1\le i\le m}\max_{1\le j\le n} HD\left(nq_{ij}, NCNNIS_j\right)}{HD\left(nq_{ij}, NCNNIS_j\right) + \rho \max_{1\le i\le m}\max_{1\le j\le n} HD\left(nq_{ij}, NCNNIS_j\right)} \tag{22}$$

Step 5: Design the grey relation degree information from NCNPIS and NCNNIS:

$$PISGRD\left(YY_i\right) = \sum_{j=1}^{n} wz_j PISGRC\left(YY_{ij}\right) \tag{23}$$

$$NISGRD\left(YY_i\right) = \sum_{j=1}^{n} wz_j NISGRC\left(YY_{ij}\right) \tag{24}$$

Step 6: Design the relative relational degree information (NCNRRD) from NCNPIS:

$$NCNRRD(YY_i) = \frac{NISGRD(YY_i)}{PISGRD(YY_i) + NISGRD(YY_i)} \tag{25}$$

Step 7: From the $NCNRRD(YY_i)$. The higher value of $NCNRRD(YY_i)$ represents the better choice.

NUMERICAL EXAMPLE AND COMPARATIVE ANALYSIS

Numerical Example

In the digital age, the evaluation of communication effectiveness for Huimo production craftsmanship transcends mere quantitative metrics, entering a more nuanced domain of cultural continuity, technological adaptation, and societal engagement. This traditional art form, with its profound historical roots and intricate manufacturing processes, faces both unprecedented opportunities and challenges in the digital era. The dissemination of such intangible cultural heritage is no longer confined to physical workshops, oral instruction, or regional exhibitions; instead, it unfolds across digital platforms, virtual demonstrations, social media narratives, and online educational modules. Therefore, evaluating its communication effectiveness must consider not only reach and exposure but also deeper dimensions of understanding, appreciation, and cultural resonance. Digitization enables broader and more immersive storytelling. Through high-definition videos, interactive websites, and 3D visualizations, the once obscure and geographically restricted craft becomes accessible to global audiences. However, effective communication is not merely about visibility—it is about meaning. Success should be measured by the audience's ability to grasp the cultural significance, aesthetic subtlety, and technical sophistication behind Huimo production. It also involves assessing how digital mediums facilitate emotional connection and sustained interest rather than passive consumption. Moreover, the role of community interaction must be emphasized. Digital platforms allow for dynamic dialogue between inheritors of the craft, scholars, enthusiasts, and general viewers. Effective communication fosters a sense of participation—for instance, through live Q&A sessions, virtual try-on experiences, or user-generated content—which strengthens the perceived relevance of traditional craftsmanship in modern life. Ultimately, evaluating the communication effectiveness of Huimo production in the digital age involves analyzing whether digital strategies honor the authenticity of the craft while innovating its narrative form. It is about building bridges between heritage and contemporary viewers, ensuring that technological adoption enhances rather than diminishes cultural value. The true measure lies in the cultivation of an informed, appreciative, and engaged global audience that value and sustains this cultural practice for future generations.

In this study, the communication effectiveness evaluation of Huimo production techniques in the digital age was viewed as MADM. Five potential Huimo production communication platforms $YY_i(i= 1,2,3,4,5)$ were designed with four attributes:

ZZ_1 was *digital reach and engagement*. This metric assessed the extent and intensity of audience interaction with digital content related to Huimo craftsmanship. It included quantitative measures such as page views, video watch time, social media shares, and download rates of related apps or digital resources. More importantly, it evaluated the depth of engagement—how long users stay with the content, whether they participate in comments or discussions, and if they actively seek further information. High reach with low engagement may indicate superficial exposure, whereas sustained interaction suggests effective content resonance.

ZZ_2 was *cultural comprehension and educational impact.* Beyond mere visibility, this indicator evaluated how well digital platforms facilitate a deeper understanding of the cultural, historical, and technical values of Huimo production. It can be measured through user feedback surveys, quiz

completions in e-learning modules, and the quality of audience inquiries. Effective communication should translate complex traditional knowledge into accessible digital narratives without losing authenticity, fostering informed appreciation among diverse and often non-specialist viewers.

ZZ_3 was emotional connection and perception change. This dimension captured the affective impact of digital dissemination. Through sentiment analysis of comments, shares, and reviews, as well as structured feedback collection, this metric gauged whether audiences develop a stronger emotional bond with the cultural heritage. It examined shifts in public perception—for instance, whether viewers see Hui ink not merely as a historical artifact but as a living tradition with contemporary relevance.

ZZ_4 was *behavioral impact and participation level*. The ultimate test of communication effectiveness lies in whether exposure leads to action. This metric tracked tangible outcomes such as attendance at online workshops or physical exhibitions, purchases of ink products, growth in membership of relevant cultural communities, or an increase in volunteers and learners. High participation rates signify that digital communication has successfully motivated the audience to move from passive consumption to active involvement—a critical indicator of sustainable cultural transmission.

To obtain the optimal Huimo production communication platforms, the NCN-GRA framework was designed for MADM.

Step 1: Design the NCN-matrix $QQ = \left(qq_{ij}\right)_{5\times4}$, as shown in Table 1).

Table 1. Neutrosophic Cubic Number-Matrix QQ

	ZZ_1	ZZ_2
YY_1	{([0.23, 0.87], [0.14, 0.59], [0.36, 0.68]), (0.45, 0.27, 0.53)}	{([0.62, 0.89], [0.18, 0.47], [0.29, 0.75]), (0.71, 0.25, 0.44)}
YY_2	{([0.17, 0.84], [0.26, 0.53], [0.39, 0.71]), (0.51, 0.29, 0.57)}	{([0.63, 0.84], [0.19, 0.46], [0.32, 0.74]), (0.73, 0.28, 0.49)}
YY_3	{([0.31, 0.78], [0.15, 0.62], [0.43, 0.69]), (0.54, 0.32, 0.58)}	{([0.67, 0.85], [0.21, 0.49], [0.34, 0.77]), (0.75, 0.31, 0.52)}
YY_4	{([0.27, 0.82], [0.18, 0.64], [0.41, 0.73]), (0.56, 0.34, 0.62)}	{([0.69, 0.86], [0.23, 0.51], [0.36, 0.72]), (0.77, 0.33, 0.54)}
YY_5	{([0.33, 0.79], [0.19, 0.66], [0.45, 0.75]), (0.59, 0.36, 0.65)}	{([0.71, 0.83], [0.24, 0.54], [0.38, 0.78]), (0.79, 0.35, 0.57)}
	ZZ_3	ZZ_4
YY_1	{([0.35, 0.72], [0.22, 0.56], [0.43, 0.81]), (0.57, 0.38, 0.63)}	{([0.19, 0.65], [0.31, 0.54], [0.42, 0.78]), (0.48, 0.33, 0.59)}
YY_2	{([0.41, 0.79], [0.24, 0.58], [0.37, 0.82]), (0.59, 0.35, 0.61)}	{([0.28, 0.67], [0.33, 0.55], [0.44, 0.76]), (0.52, 0.41, 0.64)}
YY_3	{([0.38, 0.74], [0.25, 0.61], [0.46, 0.83]), (0.62, 0.39, 0.67)}	{([0.22, 0.71], [0.35, 0.57], [0.48, 0.79]), (0.55, 0.43, 0.66)}
YY_4	{([0.42, 0.76], [0.27, 0.63], [0.49, 0.84]), (0.64, 0.42, 0.69)}	{([0.25, 0.68], [0.37, 0.58], [0.51, 0.81]), (0.58, 0.45, 0.71)}
YY_5	{([0.48, 0.77], [0.28, 0.65], [0.52, 0.86]), (0.66, 0.44, 0.72)}	{([0.29, 0.73], [0.39, 0.62], [0.54, 0.82]), (0.61, 0.47, 0.74)}

Step 2: Normalize the $QQ = \left(qq_{ij}\right)_{5\times4}$ to $NQ = \left[nq_{ij}\right]_{5\times4}$. Since all attributes were benefit-type indicators, this step was omitted.

Step 3: Design the weight information, as shown in Table 2.

Table 2. The Weight Information

	ZZ_1	ZZ_2	ZZ_3	ZZ_4
Weight	0.2192	0.3058	0.2453	0.2297

Step 4: Design the NCNPIS and NCNNIS, as shown in Table 4.

Table 4. Neutrosophic Cubic Number Positive Ideal Solution and Neutrosophic Cubic Number Negative Ideal Solution

	$\boldsymbol{ZZ_1}$	$\boldsymbol{ZZ_2}$
NCNPIS	{([0.33, 0.79], [0.19, 0.66], [0.45, 0.75]), (0.59, 0.36, 0.65)}	{([0.71, 0.83], [0.24, 0.54], [0.38, 0.78]), (0.79, 0.35, 0.57)}
NCNNIS	{([0.17, 0.84], [0.26, 0.53], [0.39, 0.71]), (0.51, 0.29, 0.57)}	{([0.62, 0.89], [0.18, 0.47], [0.29, 0.75]), (0.71, 0.25, 0.44)}
	$\boldsymbol{ZZ_3}$	$\boldsymbol{ZZ_4}$
NCNPIS	{([0.48, 0.77], [0.28, 0.65], [0.52, 0.86]), (0.66, 0.44, 0.72)}	{([0.29, 0.73], [0.39, 0.62], [0.54, 0.82]), (0.61, 0.47, 0.74)}
NCNNIS	{([0.35, 0.72], [0.22, 0.56], [0.43, 0.81]), (0.57, 0.38, 0.63)}	{([0.19, 0.65], [0.31, 0.54], [0.42, 0.78]), (0.48, 0.33, 0.59)}

Note. NCNPIS = NCN positive ideal solution; NCNNIS = NCN negative ideal solution.

Step 5: Design the $PISGRC(\xi_{ij})$ and $NISGRC(\xi_{ij})$, as shown in Tables 5 and 6.

Table 5. The $PISGRC(\xi_{ij})$

Alternatives	ZZ_1	ZZ_2	ZZ_3	ZZ_4
YY_1	0.8268	0.5612	0.4531	0.5346
YY_2	0.6789	0.5612	0.5431	0.6254
YY_3	0.8507	0.8268	0.5431	0.6134
YY_4	0.6508	0.6254	0.5612	0.6508
YY_5	1.0000	1.0000	1.0000	1.0000

Table 6. The $NISGRC(\xi_{ij})$

Alternatives	ZZ_1	ZZ_2	ZZ_3	ZZ_4
YY_1	0.9369	1.0000	1.0000	1.0000
YY_2	1.0000	0.9369	0.8663	0.8737
YY_3	0.8513	0.7665	0.9909	0.8663
YY_4	0.6381	0.8299	0.8238	0.7463
YY_5	0.6309	0.8663	0.8994	0.8916

Step 6: Design the $PISGRC(\xi_{ij})$ and $NISGRC(\xi_{ij})$, as shown in Table 7.

Table 7. The $PISGRC(\xi_{ij})$ and $NISGRC(\xi_{ij})$

	$PISGRC(\xi_{ij})$	$NISGRC(\xi_{ij})$
YY_1	0.5868	0.9862
YY_2	0.5973	0.9189
YY_3	0.7134	0.8631
YY_4	0.6211	0.7672
YY_5	1.0000	0.8286

Step 7: Design the $NCNRRD(\xi_i)$, as shown in Table 8.

Table 8. The $NCNRRD(\xi_i)$

	$NCNRRD(\xi_i)$	Order
YY_1	0.3730	5
YY_2	0.3939	4
YY_3	0.4525	2
YY_4	0.4474	3
YY_5	0.5469	1

Step 8: From the $NCNRRD(\xi_i)$, the order was designed: $YY_5 > YY_4 > YY_3 > YY_2 > YY_1$. Thus, YY_5 was the best Huimo production communication platform.

Comparative Analysis and Results Discussion

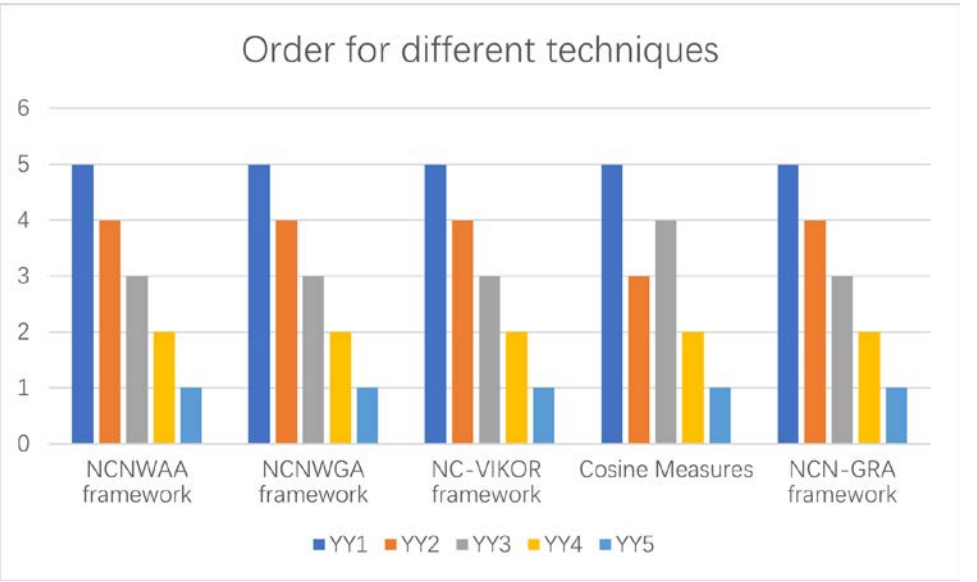
The NCN-GRA framework was compared with NCNWAA framework and NCNWGA framework (Ye, 2018), NCN-VIKOR framework (Pramanik et al., 2018) and cosine measures (Lu & Ye, 2017). The comparative results are shown in Table 9 and Figure 2.

Table 9. The Comparative Results

Approaches	Order
NCNWAA framework (Ye, 2018)	$YY_5 > YY_4 > YY_3 > YY_2 > YY_1$
NCNWGA framework (Ye, 2018)	$YY_5 > YY_4 > YY_3 > YY_2 > YY_1$
NC-VIKOR framework (Pramanik et al., 2018)	$YY_5 > YY_4 > YY_3 > YY_2 > YY_1$
Cosine Measures (Lu & Ye, 2017)	$YY_5 > YY_4 > YY_2 > YY_3 > YY_1$
NCN-GRA framework	$YY_5 > YY_4 > YY_3 > YY_2 > YY_1$

Note. NCN-GRA = neutrosophic cubic number-based grey relational analysis; NCNWAA = neutrosophic cubic number weighted average; NCNWGA = neutrosophic cubic number weighted geometric average; NC-VIKOR = neutrosophic cubic number VIKOR.

Figure 2. The Comparative Results



Note. NCN-GRA = neutrosophic cubic number-based grey relational analysis; NCNWAA = neutrosophic cubic number weighted average; NCNWGA = neutrosophic cubic number weighted geometric average; NC-VIKOR = neutrosophic cubic number VIKOR.

According to the results in Table 9, the optimal alternative was determined to be YY_5, whereas the least desirable was YY_1. The evaluation frameworks examined offer varied methodologies for tackling MADM challenges, each contributing unique strengths to the assessment of innovation and entrepreneurship competencies among college students within the context of industry-education integration.

The NCNWAA and NCNWGA models emphasize systematic information integration, ensuring all attribute influences are proportionally reflected in the final outcome. In contrast, the NCN-VIKOR method adopts a compromise-based strategy, measuring each alternative's closeness to the ideal solution and its remoteness from the negative ideal, thereby facilitating balanced trade-offs in conflicting criteria. Meanwhile, the NCN-GRA framework employs grey relational analysis to evaluate similarity between data sequences based on geometric curve resemblance. This method

requires fewer computational resources, operates effectively with limited data, and aligns well with qualitative expert judgment, enhancing interpretive consistency.

In summary, each framework offers distinct advantages: NCNWAA and NCNWGA excel in holistic data aggregation, NCN-VIKOR supports ideal solution benchmarking, and NCN-GRA provides efficient and interpretable relational analysis, together forming a versatile toolkit for MADM applications.

The communication effectiveness evaluation of Huimo production techniques in the digital age is essential for bridging higher education and contemporary industry needs. Under the framework of industry-education integration—where academic and practical training converge—it becomes crucial to implement flexible and resilient assessment tools. Conventional methods often fall short in handling the inherent uncertainties and multidimensional nature of such evaluations. The proposed framework not only overcomes these limitations but also facilitates stronger educational–industrial collaboration, thereby strengthening students' innovation and entrepreneurial competencies.

Management Implications

The proposed framework delivers a solid structure for assessing innovation and entrepreneurial capabilities while generating actionable insights for educational administration, practice, and policy design. By overcoming the shortcomings of conventional models, it helps align academic training with industrial requirements. The incorporation of advanced decision-support mechanisms guarantees both conceptual soundness and real-world relevance, establishing it as a pertinent instrument within contemporary education. Based on these advantages, the subsequent implications underscore its theoretical, practical, and policy-related relevance.

The integration of NCSs and GRA offers a theoretically robust decision-making tool that enhances the objectivity and comprehensiveness of evaluating intangible cultural heritage dissemination. This method provides a structured framework to handle uncertainty and conflicting criteria, making it particularly suitable for assessing multidimensional digital communication strategies. Theoretically, it advances the application of neutrosophic decision-making in cultural preservation, offering a replicable model for similar domains.

Practically, the NCN-GRA model enables cultural institutions and educational organizations to systematically assess and optimize digital communication efforts, such as content engagement, audience reach, and educational impact. By incorporating the CRITIC method for objective weighting, the approach supports data-informed strategy adjustments, resource allocation, and audience segmentation, thereby improving the effectiveness of promotion initiatives for traditional craftsmanship like Hui ink-making.

From a policy perspective, this research advocates for the adoption of advanced decision-support systems in publicly funded cultural heritage projects. Policymakers and administrative bodies should encourage the use of scientifically rigorous evaluation mechanisms—such as the NCN-GRA framework—in designing, monitoring, and subsidizing digital dissemination programs. This can help maximize the return on investment in cultural digitization while ensuring authenticity, inclusivity, and sustainable engagement.

CONCLUSION

In the digital age, the evaluation of communication effectiveness for Hui ink-making craftsmanship extends beyond quantitative metrics to encompass cultural resonance, technological adaptation, and public engagement. Digital platforms—such as immersive virtual demonstrations, social media narratives, and online educational content—enable global accessibility and richer storytelling. However, effective dissemination is not merely about visibility; it hinges on fostering meaningful audience understanding, emotional connection, and sustained interest in this traditional art form. Success is reflected in the audience’s deepened appreciation of its cultural significance

and technical sophistication, as well as active participation across digital channels. Ultimately, such evaluation examines how well digital strategies preserve authenticity while innovating engagement, ensuring the craft's relevance for future generations. The communication effectiveness evaluation of Huimo production techniques in the digital age constitutes a MADM challenge. This study presented an innovative NCN-GRA approach, which expanded conventional GRA through integration with NCSs. The proposed model was developed to handle intricate decision scenarios involving uncertainty, ambiguity, and contradictory information. To achieve impartial and precise weighting of evaluation attributes, the CRITIC technique was utilized, capitalizing on inter-attribute correlations and variability to objectively quantify their relative importance. Designed specifically for MADM applications, the NCN-GRA framework included a systematic breakdown of its computational steps to facilitate implementation in real-world contexts. Its applicability was verified through a case study examining innovation and entrepreneurship competencies among university students within the industry-education integration paradigm. The model effectively incorporates multifaceted criteria—including practical skill acquisition, student engagement, industry relevance, and comprehensive educational outcomes—enabling a nuanced and well-rounded assessment. The findings underscore the model's proficiency in navigating the complex, multidimensional demands of contemporary education. It offers a resilient and flexible methodology capable of supporting informed and balanced decision-making in evolving academic and industrial settings.

The primary contributions of this research in assessing the digital communication efficacy of Huimo production techniques are summarized below:

- Employing the CRITIC method enables an objective determination of attribute weights, promoting an impartial and precise evaluation that accurately represents the importance of each criterion.
- A novel NCN-GRA technique was formulated within the structure of NCSs, enhancing its capacity to process uncertainty, imprecision, and intricate data inherent in practical decision-making. By advancing conventional GRA, the model offers improved versatility and performance in MADM contexts.
- The real-world utility of the NCN-GRA approach was validated via a case study centered on the digital dissemination of Hui ink craftsmanship. This application illustrates the model's proficiency in addressing complex assessment challenges through the integration of multiple interrelated indicators. Additionally, comparative evaluations underscore the superiority of NCN-GRA over established methods, demonstrating higher computational efficiency, adaptability, and consistency in producing dependable outcomes for educational policy and practice.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

CORRESPONDING AUTHOR

Correspondence should be addressed to Hong Tang (China, tangh11023@163.com).

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